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TECHNOLOGY DEVELOPMENT AND TESTING FOR ENHANCED MARS ROVER FUNCTIONALITY

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Even before Sojourner had made its first wheel tracks on Mars, it was anticipated that this rover would only be the first of a series of surface exploration spacecraft targeted for this planet. While it will be Sojourner's flight spare that drives on Mars in 2002, the next leap in technical capability exhibited by rovers will be in the 2003/2005 mission set, where much larger rovers will perform rock and soil sample collection for return to Earth. These rovers will have greater innate capabilities, opening the door for the insertion of new robotics technologies that have been in development since the inception of the Pathfinder mission five years ago. Amongst these are: on-board stereo vision processing, autonomous landerless operations, manipulation and instrument positioning by arms, precision navigation for rover/lander rendezvous, and distributed ground operations.

Of fundamental importance to the incorporation of the new capabilities on next generation rovers is the use of a more capable electronics, sensing and instrumentation infrastructure located on-board the rover. For instance, as Sojourner was being prepared for flight, JPL was constructing a new prototype, Rocky 7. Several key features were added to support long trips away from the lander: a deployable mast to raise cameras and take panoramic images of the surrounding terrain, a shorter arm for sample acquisition and instrument placement, and a sun sensor to accurately determine heading during driving. These features were demonstrated in a series of field test in the Mojave Desert in 1997, which led directly to the acceptance of the 03/05 missions.

However, the 03/05 mission concept selected requires an enlarged rover that has the added functionality of carrying a drill for rock sampling, larger wheels for enhanced mobility, and a significantly upgraded science instrument suite (as opposed the Sojourner rover). Therefore, to support continued field tests with the selected science team for the 03/05 mission, a new Field Integrated Design and Operations (FIDO) rover was conceived, designed, integrated during a 12 month period and demonstrated in desert tests in April, 1999. The FIDO rover reflects the current engineering sensors and science instrument suite that are planned for the 03/05 mission. While this rover will continue to act as an operations testbed for mission scientists, it has a second function as an integration testbed for new technologies that continue to be developed in ongoing research efforts.

These research efforts are supported by the JPL core robotics technology program which include the Rocky 7 rover, as well as another platform, the Sample Return Rover (SRR). Recently these rovers have each been dedicated to increasing autonomy in two respective halves of the exploration problem: autonomous motion away from and back to the lander. New techniques employed include estimation and visual localization, on-board path and sequence re-planning, and natural and man-made target recognition and tracking.

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Dynamic pair breaking in cuprate superconductors via injection of spin-polarized quasiparticles in perovskite F-I-S heterostructures

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Abstract

We report experimental evidence of dynamic Cooper pair breaking induced by spin-polarized quasiparticles in cuprate superconductors by studying the critical current density and quasiparticle density of states of ferromagnet-insulator-superconductor (F-I-S) heterostructures. The spin diffusion length and relaxation time are also estimated.

Non-equilibrium superconductivity has been extensively studied since the 1970's [1]. Most of the investigation has focused on the effects of simple quasiparticle (QP) injection and extraction in conventional s-wave superconductors. In contrast, there is insufficient theoretical understanding of spin-polarized QP transport in superconductors, largely due to the complications of combined non-equilibrium [1] and magnetic pair-breaking effects [2] induced by spin-polarized currents. Recently, the concept of spin injection has been investigated in high-temperature superconductors (HTS) by passing an electrical current through a perovskite ferromagnetic manganite to introduce spin-polarized quasiparticles (QP's) [3,4]. However, the reported suppression of critical currents in the perovskite ferromagnet-insulator-superconductor (F-I-S) appear to be primarily induced by Joule heating. To amend this problem, we adopted a pulsed current technique and in-situ thermometry [5], so that the effect of Joule heating is limited to < 10 mK. In this work, we report macroscopic and microscopic experimental evidence of dynamic pair breaking induced by spin-polarized QP currents in perovskite F-I-S heterostructures. These results are compared with control samples of N-I-S heterostructures (N: non-magnetic metal).

The F-I-S and N-I-S samples are fabricated using the pulsed-laser deposition technique [5]. The chemical formulae and thicknesses of the constituent layers are:

- **F:** $La_{0.7}Ca_{0.3}MnO_3$ (LCMO) and $La_{0.7}Sr_{0.3}MnO_3$ (LSMO), 100 nm.
- **I:** $SrTiO_3$ (STO), 2.0 nm; and yttria-stabilized-zirconia (YSZ), 1.3 nm.
- **N:** $LaNiO_3$ (LNO), 100 nm.
- **S:** $YBa_2Cu_3O_7$ (YBCO), 100 nm.

The effect of spin-polarized current I_m on the critical current density (J_c) of YBCO is shown in Figure 1(a), and the absence of effect in the N-I-S sample is illustrated in Figure 1(b). We note that the suppression of J_c in F-I-S becomes significant only

[1] Corresponding author. E-mail: ncyeh@caltech.edu . This work is jointly supported by NSF and NASA/OSS.

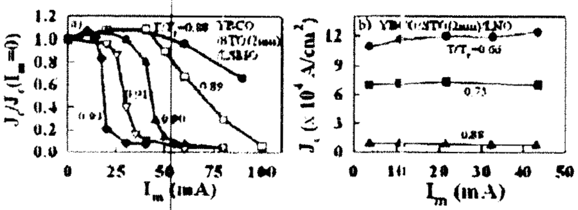

Fig. 1. (a) Effect of the spin-polarized quasiparticle current (I_m) on the J_c of YBCO in an F-I-S heterostructure. (b) Independence of J_c on injection in an N-I-S control sample.

near T_c, due to the diverging QP relaxation time [1]. In analogy to the simple QP relaxation through inelastic electron-phonon scattering [1], we may assume a relaxation process of spin-polarized QP's through the spin exchange interaction. The relaxation time is given by $\tau_s(T) \sim 3.7\tau_{ex}k_BT_c/\langle\Delta(T)\rangle$, where $\tau_{ex} \sim (\hbar/E_{ex})$ is the interaction time associated with the exchange energy $E_{ex} \sim 30$ K in YBCO [5]. Hence, for an average d-wave superconducting energy gap $\langle\Delta(T)\rangle \approx \Delta_d[1-(T/T_c)]^{1/2}$ with $\Delta_d \sim 20$ meV, we obtain $\tau_s \sim 3\times10^{-13}[1-(T/T_c)]^{-1/2}$s. The spin diffusion length ℓ_s may be estimated by $\ell_s \approx \sqrt{\ell_0 v_F \tau_s}$, where ℓ_0 is the electron mean free path, and v_F is the Fermi velocity [1]. For $v_F \sim 10^5$ m/s and $\ell_0 \sim 20$ nm, we find that $\ell_s \sim 25$ nm for $T \to 0$ and $\ell_s \sim 80$ nm ($\sim$ sample thickness) at $[1-(T/T_c)] \sim 0.01$. This estimate is consistent with the observed strong dependence of J_c on I_m in F-I-S only near T_c.

The main panel of Figure 2(a) illustrates the differential conductance (dI/dV) versus bias voltage (V) data of YBCO, taken with a low-temperature STM, for c-axis tunneling at 4.2 K and under various I_m. The inset shows the dependence of QP density of states (DOS) on I_m at the Fermi level ($V=0$). The spectra appear invariant for I_m up to 35 mA [6], above which spectral smearing appears, showing excess QP-DOS near the zero bias, which is consistent with Cooper pair breaking. The threshold current $I_m^* \sim 35$ mA corresponds to an injection energy $(eI_m^*R_J) \approx 21$ meV, comparable to Δ_d for a measured junction resistance $R_J \approx 0.6\Omega$. At higher I_m, the QP-DOS may be fitted to an effective QP temperature ($T^* \sim 60$ K), even under negligible Joule heating [6]. In contrast, spec-

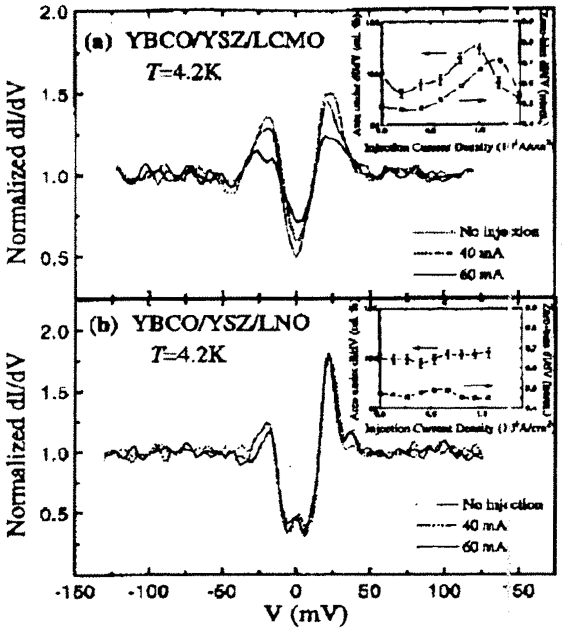

Fig. 2. STM spectroscopy data taken at 4.2 K on (a) F-I-S and (b) N-I-S samples under varying I_m, showing nonconserved spectral area and nonuniform zero-bias conductance for the former, (inset of (a)), and relative spectral invariance for the latter, (inset of (b)).

tral studies of YBCO in the N-I-S sample exhibit no detectable dependence on the injection, as shown in the main panel and the inset of Figure 2(b). These results suggest that spin-polarized QP's are strong "pair breakers". More investigation is underway to determine relevant physical parameters associated with the dynamic pair breaking and quasiparticle tranport in cuprate superconductors.

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